Electromagnetic Propagation

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LONG TERM GOALS

Develop electromagnetic propagation models for use in operational or engineering propagation assessment systems.

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OBJECTIVES

Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Resolve differences between current techniques used to model propagation effects under rough surface and strong ducting conditions.

APPROACH

We develop parabolic equation, ray optics, waveguide, and other models as necessary to produce both accurate and efficient models to be used in propagation assessment systems. In many cases we can use variations of existing models to achieve this goal, but sometimes completely new models are necessary. Once developed, these models are compared to other models and to experimentally collected propagation data for verification of accuracy. We stay abreast of other researchers' newest models by reading current literature, participating in propagation workshops, and attending conferences as appropriate. There is a strong international exchange of ideas and techniques in this area, as some important work is performed outside of the USA. This project is divided into two tasks: (1) Propagation over Terrain, and (2) Rough Surface Effects.

WORK COMPLETED

PROPAGATION OVER TERRAIN

Work in FY98 consisted of substantial improvements to APM, investigation of current PE techniques to model infrared (IR) transmission and an analysis of measured IR transmission, coordination of data analysis for a NATO-sponsored multi-national radar experiment, and analyses of two different data sets with respect to the ability to statistically predict mean signal level distributions.

Substantial improvements were made to APM, in particular to include airborne sources and to implement the best available, though still not validated, PE rough surface model originally developed by Kuttler and Dockery from JHU/APL. A paper on APM was prepared and delivered to the Battlespace Atmospherics Conference (BAC) in December 1997.

A special version of the PE sub model of APM was developed for infrared transmission for comparison to transmission measurements made under the Electrooptical Propagation Assessment in Coastal Environments (EOPACE) program. A paper on this topic was prepared jointly with members of the EOPACE team for BAC in December 1997.

Coordination was provided for data analysis of the Livorno multi-national radar experiment, and contributions were made to a NATO-sponsored conference that reviewed RSG-21's efforts. In addition, the chapter on propagation for the final report of RSG-21's efforts was prepared.

An analysis of two different data sets with respect to the ability to statistically predict mean signal level distributions was performed. The data were from the Lorient, France and Wallops Island, Virginia coastal areas. These results were presented at CLIMPARA '98 in April 1998.

ROUGH SURFACE EFFECTS

Work in FY98 consisted of analyzing data from previous radio propagation experiments specifically for rough sea surface effects, participating in the Wallops Island 1998 propagation experiment conducted by NSWC Dahlgren Division, and an analytical investigation of the relationship between rough surface effects at low grazing angles and the effective impedance of the surface.

A total of four previous radio propagation experiments dominated by the evaporation duct were analyzed. The areas were the Greek Islands, Catalina to San Clemente Islands in southern California, Parramore Island to Wallops Island, Virginia, and the North Sea along the coast of The Netherlands. The Greek and California islands experiments were analyzed in depth for the 37 GHz frequency and papers were prepared and presented at the Battlespace Atmospherics Conference (BAC) in December 1997 and at URSI in January 1998. Rough sea surface effects were clearly encountered in these two experiments and the comparisons between observed and modeled results were reasonably good at the lowest antenna heights. However there is an unexplained divergence between modeled and experimental results of about 1 dB per meter of terminal antenna height above the surface. The source of this discrepancy is not known. It may be experimental error in either the radio or the meteorological data or it may be an error in the models. In these two experiments only moderately high evaporation duct heights and wind speeds were encountered, thus rough surface effects were only noticed at the highest frequency of 37 GHz. The lower frequencies of 18 GHz and below did not show any significant rough surface effects, as would be expected. Modeling of effects at 37 GHz is complicated by the requirement to also account for the gaseous absorption mechanism, which accounted for about 5 to 6 dB for the paths in question. The other two experiments, at Wallops Island, Virginia in 1994 and The Netherlands in 1988, did apparently experience higher duct heights and wind speeds. Preliminary analyses were performed for these experiments from published data and more complete analyses are planned for FY99.

SSC SD personnel participated in the “Wallops Island 1998” propagation experiment, and the resulting data were analyzed specifically looking for rough surface effects. This experiment measured propagation loss from 2 to 17 GHz between transmitters on a boat and receivers on Wallops Island. Simultaneous measurements were made for 10 transmitter heights from about 1 to 10 meters and 4 receiver heights from about 5 to 24 meters using the NSWCDD Microwave Propagation Measurement System (MPMS). Good supporting meteorological measurements were made from buoys, the boat, and the shore station. Although the meteorological measurements indicated some minor rough surface effects should have been observed, no effects were found in the radio data. A paper summarizing these results was presented at the Progress in Electromagnetics Research Symposium (PIERS) in July 1998.

Assessment of rough surface effects on low grazing angle radio propagation can be accomplished if an effective impedance for the rough surface is known. Previous methods for obtaining this impedance fail when either the surface is very rough or if the frequency exceeds a few hundred MHz. This is due to the ill-posed nature of the integral equations used. An extended integral equation based on Tikhonov’s regularization scheme for em scatter/propagation over a periodic surface has been developed and numerically validated. The regularized integral equation is shown to work for frequencies through the microwave range and for surface slopes as high as 15.

RESULTS

PROPAGATION OVER TERRAIN

The primary result of this task is the development of the Advanced Propagation Model. This model is now very robust and includes a very complete set of features. It is already being widely used by fleet operational personnel and others in the Advanced Refractive Effects Prediction System.

ROUGH SURFACE EFFECTS

The current rough sea surface models in use by the majority of researchers in this area have still not been validated. These models include the SSC SD waveguide model MLAYER and the hybrid model APM, the JHU/APL PE model TEMPER, and the British hybrid model TERPEM. All are based on the Miller-Brown rough surface reflection coefficient model and some method of determining the surface grazing angle. MLAYER is considered the most mathematically rigorous of these methods since the eigen angle for each mode is directly related to grazing angle. MLAYER was used in all the analyses described above, but the findings should hold for the other models as well.

The 1988 experiment in The Netherlands and the 1994 experiment at Wallops Island appear to contain periods of strong ducting and high wind speeds, and thus are good candidates for further analysis which is planned for FY99. The preliminary analysis of the 1988 data indicates that the high wind speeds associated with very rough surfaces may be altering the vertical refractive index profile from that normally assumed, thereby resulting in weaker ducting. Such an alteration is not accounted for in any of the models, and may also be the reason for the discrepancy noted in the Greek and California island analyses.

Plans for an experiment originally planned for Hawaii and more recently considered for southern California remain on hold, pending the outcome of the above described analyses of existing data sets. If these analyses result in a conclusive validation of existing models, an experiment may not be indicated. If an experiment is indicated, these analyses should provide better guidance on designing the experiment than is currently available.

What has been learned so far from this task is that understanding rough surface effects on ducted propagation is a much more difficult problem than originally anticipated.

IMPACT/APPLICATIONS

The goal of this work is to produce the best possible hybrid radio propagation model for incorporation into U.S. Navy assessment systems. Current plans call for APM to be the single model for all applications. As APM is developed it will be properly documented for delivery to the Oceanographic and Atmospheric Master Library (OAML), from which it will be available for incorporation into Navy assessment systems. Without a model such as APM, advanced propagation assessment would not be possible.

TRANSITIONS

The primary transition path for this task is via OAML. APM has been fully documented and formally submitted to the OAML program and is currently awaiting certification. As the model is enhanced

Engineering Change Proposals (ECPs) will also be submitted to OAML to keep the model current. APM is being incorporated into the Advanced Refractive Effects Prediction System, which will become a DII COE compliant component of the Tactical Environmental Support System - Next Century (TESS-NC).

RELATED PROJECTS

This project is closely related to the synoptic and mesoscale numerical analysis and prediction projects pursued by NRL Monterey, the Coastal Variability Analysis, Measurement, and Prediction (COVAMP) project, the Remote Refractivity Sensing project under ONR 321SI, the EO-IR Sensor Diagnostics project under ONR 313, and the Tactical EM Propagation Models task under PMW 185. Tri service coordination is conducted under the Technology Area Review and Assessment.

PUBLICATIONS

Rogers, L.T., and R.A. Paulus, Publication of the Year Award, Articles in Conference Proceedings, “Measured Performance of Evaporation Duct Models,” February 1998.

Barrios, A.E., “Advanced Propagation Model,” 1997 Battlespace Atmospherics Conference, 2-4 Dec 97, San Diego, CA, Proceedings pub. SPAWARSYSCEN TD 2989, March 1998.

Hitney, H.V., “Evaporation Duct Propagation Over a Rough Sea,” 1997 Battlespace Atmospherics Conference, 2-4 Dec 97, San Diego, CA, Proceedings pub. SPAWARSYSCEN TD 2989, March 1998.

Levy, M.F., “Rough Sea Surface Effects on Ducting Propagation,” 1997 Battlespace Atmospherics Conference, 2-4 Dec 97, San Diego, CA, Proceedings pub. SPAWARSYSCEN TD 2989, March 1998.

Paulus, R.A., “Troposcatter Calculations With A Parabolic Equation Model,” 1997 Battlespace Atmospherics Conference 2-4 Dec. 97, San Diego, CA, Proceedings pub. SPAWARSYSCEN TD 2989, March 1998.

Paulus, R.A., and K.D. Anderson, “Applications of an Evaporation Duct Climatology,” Proc. URSI Comm. F Open Symp. CLIMPARA '98, Ottawa, Canada, pp. 104-107, April 1998.

Janaswamy, R., “A curvilinear coordinate based, split-step parabolic equation approach for propagation predictions over terrain,” IEEE Trans. Antennas Propagat., Vol. 46, No. 7, July 1998.

Hitney, H.V., “Validation of models for rough surface ducting cases,” PIERS '98 Symposium, July 1998.

“Environmental Effects on Radar Signature of Ships: the Livorno '96 Campaign Propagation and Effects,” Chapter 3, NATO AC323 Sensor and Electronics Technology Subgroup Report, 1998.

Janaswamy, R., “Towards Extracting an Effective Impedance for Low Grazing Angle Propagation Over Rough Surface,” Draft NPS Technical Report NPS-EC-98-xxx, October 1998.

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